

NICMOS Imaging of High-Redshift Radio Galaxies

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Abstract. We have obtained near-infrared ($1.6\ \mu\text{m}$) images of 11 powerful 3CR radio galaxies at redshifts $0.8 < z < 1.8$ using NICMOS on board HST. The high angular resolution permits a detailed study of galaxy morphology in these systems at rest-frame optical wavelengths, where starlight dominates over the extended, aligned UV continuum. The NICMOS morphologies are mostly symmetric and are consistent with dynamically relaxed, elliptical host galaxies dominated by a red, mature stellar population. The aligned structures are sometimes faintly visible, and nuclear point sources may be present in a few cases which manifest the “unveiled” AGN that is obscured from view at optical wavelengths. Our observations are consistent with the hypothesis that the host galaxies of $z \approx 1 - 2$ radio galaxies are similar to modern-day gE galaxies. Their sizes are typical of gE galaxies but smaller than present-day cD and brightest cluster galaxies, and their surface brightnesses are higher, as expected given simple luminosity evolution.

1. Introduction

At one time, radio sources offered the only readily available means of locating galaxies at large redshifts ($z > 1$), and were thus studied as a window on the early history of galaxy evolution. Radio galaxies obey a tight near-infrared Hubble ($K-z$) relation and are frequently associated with rich cluster environments. This suggests that there is an evolutionary sequence linking high-redshift radio galaxies to low-redshift giant ellipticals and cD galaxies. The discovery that many high-redshift radio galaxies have elongated, complex UV continuum structures aligned with the radio source axis (McCarthy et al. 1987; Chambers et al. 1987) suggested that the active nucleus might affect the UV morphology and possibly even the evolutionary history of the host galaxy. It was believed that some radio galaxies might be true “protogalaxies” forming the bulk of their stars via some process induced by the radio jets. However, later studies have shown that in many cases the aligned UV continuum arises largely from scattered AGN emission (Di Serego Alighieri et al. 1989) and/or nebular continuum emission (Dickson et al. 1995).

The spectacular, complex structures seen in optical WFPC2 images of 3CR radio galaxies by (e.g.) Best et al. (1997) are, in many cases, AGN-related “ephemera” surrounding a more normal host galaxy. However, the brightness

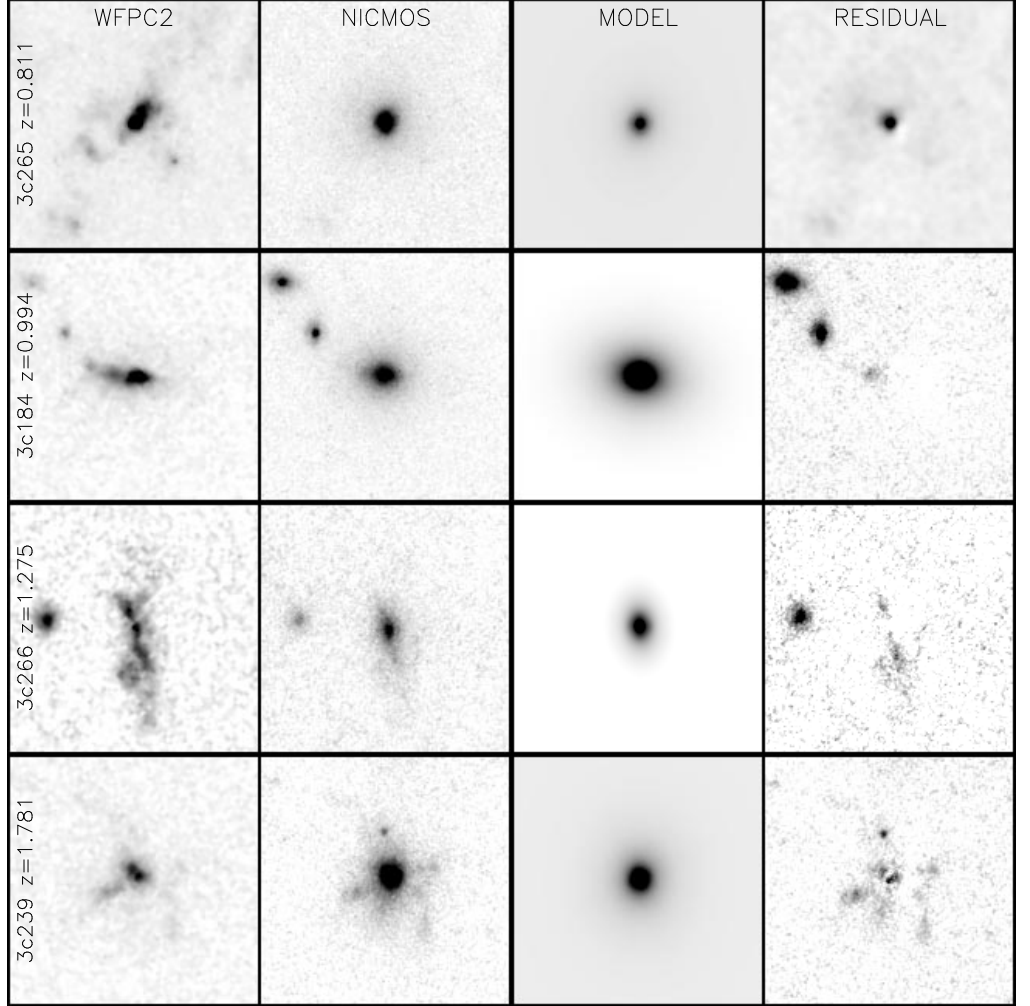


Figure 1. WFPC2 and NICMOS images of four galaxies from our NICMOS imaging sample, along with best-fitting models to the NICMOS host galaxies and the NICMOS minus model residuals.

of this aligned, blue light makes it difficult to study the properties of the underlying stellar component when observing at optical wavelengths. Observers have therefore turned to the near-IR, where the AGN-related emission is fainter and the stellar component brighter. Rigler et al. (1992), Dickinson et al. (1994) and Best et al. (1998), among others, have shown that some 3CR radio galaxies are rounder and more symmetric when observed in the near-IR, suggesting the presence of relatively “normal” host galaxies underlying the UV-bright, aligned continuum (but see also Eisenhardt & Chokshi 1990). But until now these ground-based studies have been limited by angular resolution. Now, using NICMOS on board HST, we can for the first time study the near-IR morphologies of high redshift galaxies with resolution comparable to that of the pioneering WFPC2 studies of these same objects.

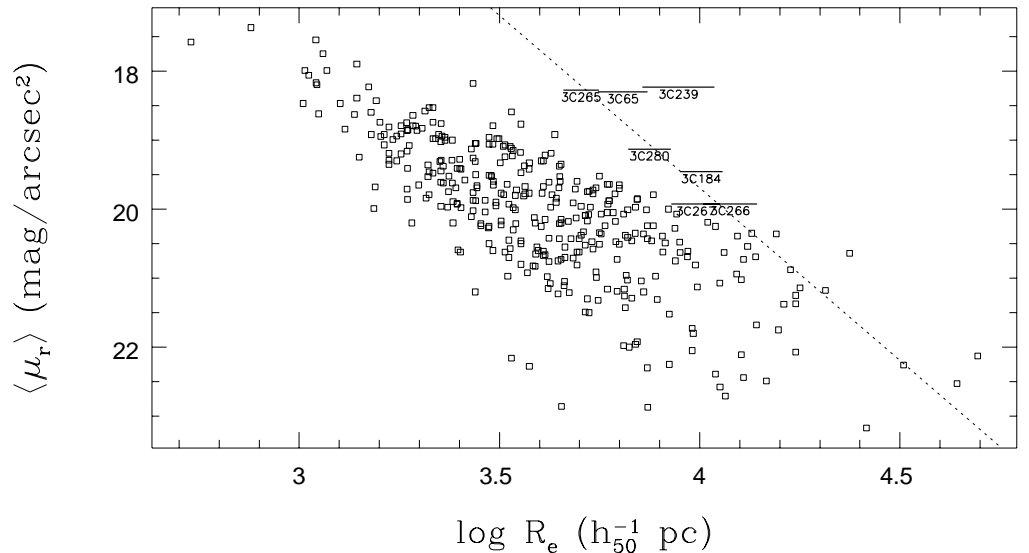


Figure 2. Rest frame Gunn r size-surface brightness relation for local cluster ellipticals (small squares; Jørgensen et al. 1995) and for our NICMOS radio galaxies (lines). The lines connect the effective radii for $q_0 = 0$ and $q_0 = 0.5$ cosmologies. The dotted line shows the relation for constant galaxy luminosity, as expected for “standard candle” galaxies.

2. Observations

Our sample consists of 11 3CR radio galaxies at $0.8 < z < 1.8$, imaged with NICMOS Camera 2, which provides diffraction limited images at $1.6\mu\text{m}$. We used bandpasses (F160W or F165M) which avoid strong nebular emission lines, which could significantly contaminate the fluxes and affect the observed morphologies. Optical WFPC2 imaging is available for the whole sample: in many cases we have unusually deep and often polarimetric WFPC2 data, while in others archival data by Best et al. 1997 or other sources were used. In most cases we also have extensive ground-based supporting data (spectroscopy, polarimetry, etc.) from the W.M. Keck Observatory and other facilities.

3. Discussion

The NICMOS and WFPC2 images of four galaxies from this sample are shown in Figure 1. We have fit PSF-convolved models to the NICMOS images using a hybrid scheme which matches 1D surface brightness profiles and 2D PA + ellipticity information. The models and the NICMOS image residuals after model subtraction are also shown in Figure 1. In most cases, the NICMOS images show that the rest-frame optical light from powerful 3CR radio galaxies at $z > 1$ is rounder, smoother, more symmetric and centrally concentrated than that observed at rest-frame UV wavelengths. The complex, aligned structures seen in WFPC2 images are generally much less pronounced in the near-IR, although in several cases (e.g. 3C 280, 3C 266, 3C 368) the highest surface brightness regions

of the aligned components can still be detected. In several cases, the near-IR surface brightness peaks at the position of a local *minimum* in the WFPC2 images, suggesting the effects of dust lanes affecting the near-UV morphologies. A few galaxies (e.g., 3C 265) appear to have nuclear point sources in the IR, possibly showing the “unveiled” AGN.

Overall, the gross morphologies and surface brightness profiles of most 3CR hosts are consistent with their being high luminosity giant elliptical galaxies, already structurally mature. This may be true as early as $z = 1.8$, although at that redshift 3C 239 appears to have “ragged edges” perhaps suggesting that it is in the process of accreting material through mergers. However, the most distant galaxy in our sample, 3C 256 at $z = 1.82$, is radically different than the others. It is elongated, aligned, diffuse, and underluminous, and thus may be the exceptional example of a young radio galaxy early in the stages of its formation (see also Eisenhardt & Dickinson 1992, Simpson et al. 1999).

In Figure 2, we plot surface brightness vs. effective radius (the “Kormendy relation”) for 6 galaxies which are well fit by $R^{1/4}$ -law models, converting the NICMOS photometry (rest-frame $\lambda_0 0.57$ to $0.88\mu\text{m}$ for our sample) to rest-frame Gunn r ($\lambda_0 0.65\mu\text{m}$) for comparison to nearby cluster ellipticals. The galaxies are physically smaller than the largest and brightest giant cluster ellipticals at $z = 0$, and have higher rest-frame surface brightnesses as would be expected given nominal luminosity evolution. Most fall on the locus of constant luminosity (see also Best et al. 1998), as might be expected given the small K - z scatter. 3C 239 at $z = 1.78$ is significantly more luminous for its size compared to the galaxies at $0.8 < z < 1.3$.

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